Evaluation of the Debris Throw from the 1992 Explosion in the Steingletscher Installation in Switzerland

Peter O. Kummer
dipl. Ing. HTL/SIA, EUR ING
BIENZ, KUMMER & PARTNER LTD, Langägertenstrasse 6
CH-8125 ZOLLIKERBERG, SWITZERLAND
Tel: int 41 1 391 27 37 FAX: int 41 1 391 27 50

Abstract:

On 2 November 1992 a detonation with an approximate force of 225 tons of TNT happened in the Steingletscher ammunition and explosives storage installation in Switzerland. Six people lost their lives in this accident. The installation was destroyed completely, the rock cover above the underground chamber broke off and rock as well as concrete pieces were thrown over a wide range into the surroundings.

Despite the tragedy of this accident the Swiss Department of Defence decided to learn as much as possible from it. Part of this effort was dedicated to the debris throw, a field where worldwide only few real data exist. This paper summarizes the work performed until now concerning debris throw from the crater above the storing chamber. It covers the following topics:

1. Introduction
2. Installation and Summary of Accident
3. Recovery and Documentation of Basic Field Data
4. Evaluation of Basic Data
5. Final Remarks

Paper presented at the 27th Department of Defense Explosives Safety Seminar in Las Vegas NV, USA on 20 - 22 August 1996

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 1996**	2. REPORT TYPE	3. DATES COVERED **00-00-1996 to 00-00-1996**

4. TITLE AND SUBTITLE **Evaluation of the Debris Throw from the 1992 Explosion in the Steingletscher Installation in Switzerland**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Bienz, Kummer & Partner Ltd,Langagertenstrasse 6,CH-8125 Zollikerberg, Switzerland,**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM000767. Proceedings of the Twenty-Seventh DoD Explosives Safety Seminar Held in Las Vegas, NV on 22-26 August 1996.

14. ABSTRACT
see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**28**	

1. Introduction

On 2 November 1992 a detonation with an approximate force of 225 tons TNT occurred in a Swiss underground installation for the storage of old ammunition and explosives prior to their destruction. Six people - all being inside the installation at the time of the explosion - lost their lives in this accident. The installation was destroyed completely, the rock cover above the underground chamber broke off and rock as well as concrete pieces were thrown over a wide range into the surroundings.

Despite the tragedy of this accident the Swiss Department of Defence decided to learn as much as possible from it. For the evaluation of the explosion effects and to study the impacts of this explosion on the existing regulations in Switzerland BIENZ, KUMMER & PARTNER was selected already in 1992 as contractor. After the Klotz-Club was informed about this accident, also US experts showed their interest and supported on their own initiative the evaluation of the effects. On behalf of the Swiss Defence Technology and Procurement Agency I would like to thank the USAF, Mr. Joseph Jenus Jr., Chief of the Explosives Hazards Reduction Program and his technical consultant, Mr. Khosrow Bakhtar, again for their valuable help.

The collection of basic data, mostly debris data, was performed during summer 1993 when the site was accessible again after the annual thaw. Unfortunately - as often in this circumstances - the legal investigation, mainly interested in the cause of the event and the responsibilities, had priority and caused a delay of years in our technical work. Only recently some of the necessary data had been made available and we therefore started with the evaluation only yet.

Part of the effort is dedicated to the debris throw, a field where worldwide only few real data exist as such tragic events are fortunately very seldom but tests very costly. As we know the installation and the contents of the chambers before the explosion quite well we have the unique opportunity to bring the knowledge of the effects of such explosions a step further and therefore contribute to the safety of new or existing ammunition storage installations.

This paper summarizes the work performed until now concerning debris throw from the crater above the storing chamber. The next chapter gives a short overview of the installation and the accident. Afterwards, the debris recovery and basic data documentation will be described. Chapter 4 contains the evaluation of the basic data, first results concerning the debris density and an estimation of expected lethalities in this environment according to the NATO and Swiss criteria. Chapter 5 gives a summary and an outlook on planned future work.

2. Installation and Summary of Accident

The magazine called "Steingletscher" (Stone-glacier) was located right in the centre of the Swiss Alps in an uninhabited area. It belonged to the Ammunition Factory Thun and was used to store old delaborated ammunition, outdated explosives and waste from the production of ammunition and explosives before their final destruction by open burning or detonation on the plain in front of the magazine. Figure 1 shows the location of the installation as well as the burning and detonation ground.

The general layout of the magazine is shown in figures 2 and 3. As it can be seen, the magazine consisted of three major parts: the two storing chambers, the unloading area (accessible for trucks) and the building at the entrance containing all the technical installations. Figures 4 and 5 document the volumina and cross-section of the different tunnel sections. The rock overburden of the storage chambers was minimally 52 m and consisted generally of very good rock, mostly granite. A more detailed description of the installation can be found in reference 3.

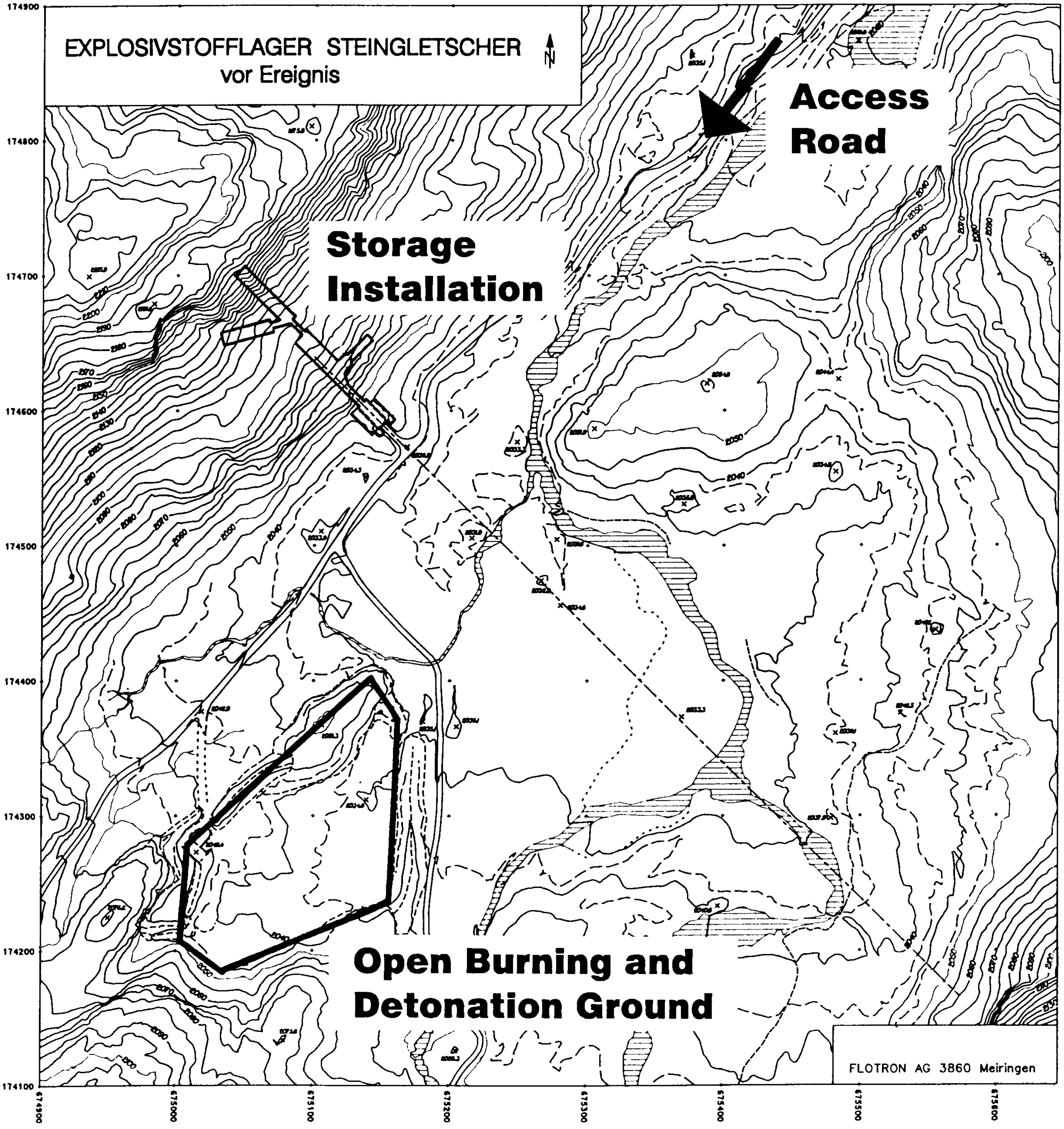
On the day of the accident the storage was loaded with about 225 tons of explosives (TNT-equivalent). The largest part - about 190 tons - was a lot of flaked TNT in cardboard drums. The average loading density in the two chambers was around 45 kg/m3.

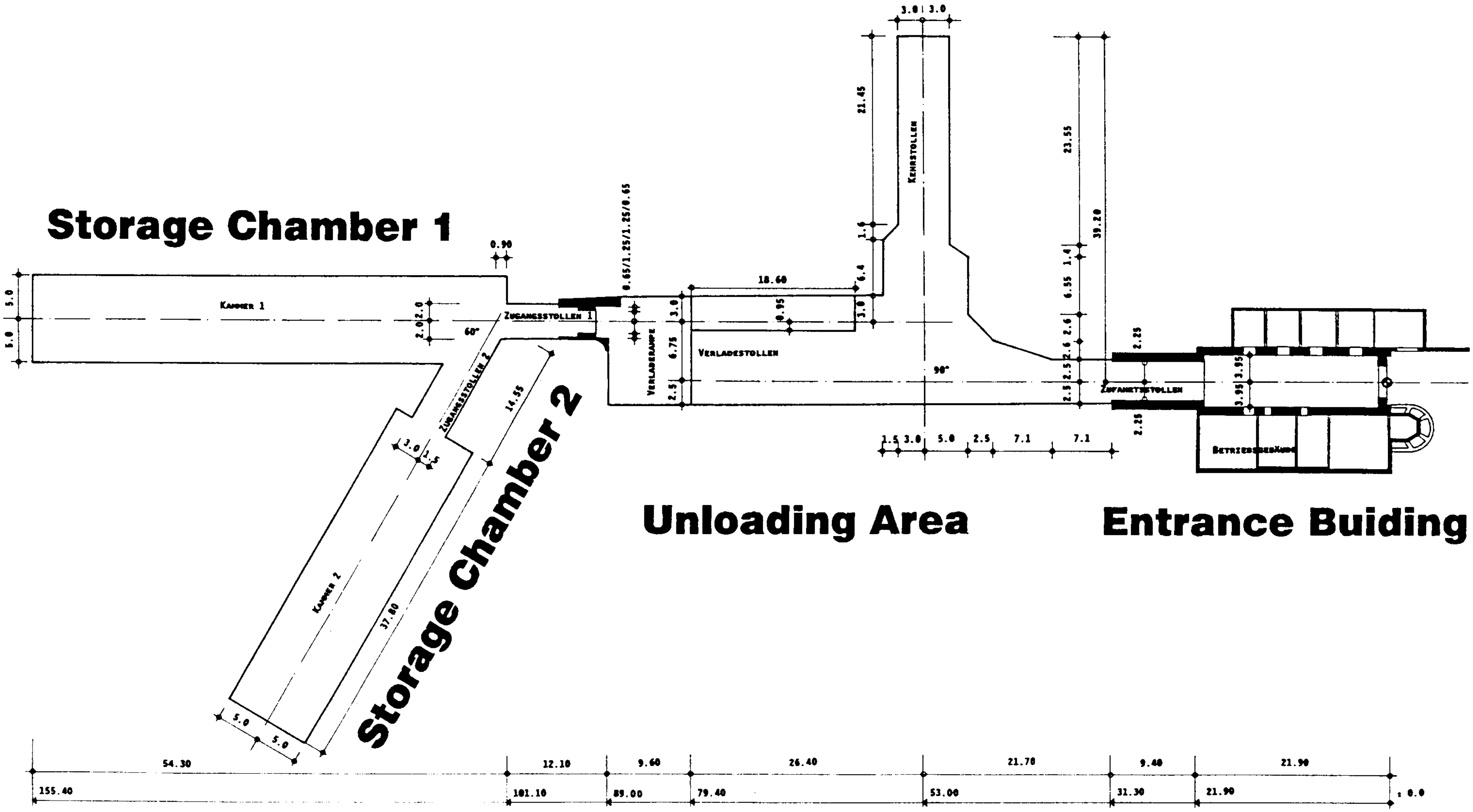
Usual operations had been underway on 2 November 1992. At the moment of the explosion six persons were working inside the installation, at least one of them in one of the storing chambers, preparing material for destruction the same afternoon. 11 people stayed in the surroundings of the installation. At about 4 p.m. a fire was reported by a worker in one of the storing chambers. Seconds later a huge explosion followed. The six people inside the installation were killed instantly, the workers in the surroundings survived without any injuries by a miracle.

The installation was destroyed completely and the force of the explosion uncovered part of the rock above the chamber. Afterwards, probably due to the ground shock and the dislocation of material due to the forming crater, a large quantity of rock material - about 100'000 m^3 - broke loose from the top of the mountain and covered the area where the installation had been located. Figure 6 shows an overview of the scenery after the explosion. Rock debris from the crater were thrown in all directions into the surrounding up to distances exceeding 500 m. In direction of the axis of the access tunnel the debris throw consisting of rock material and concrete parts from the installation - especially from the entrance building - was even more dense up to a distance of about 800 m. Figure 7 shows a concrete block from the entrance building weighing 15 tons and found 370 m from its original place. There was no damage due to air blast however, as there were no above ground structures like houses etc. in the immediate surrounding. A more detailed description of the accident can be found in references 1, 2 and 4.

Installation Before the Event

Figure 1

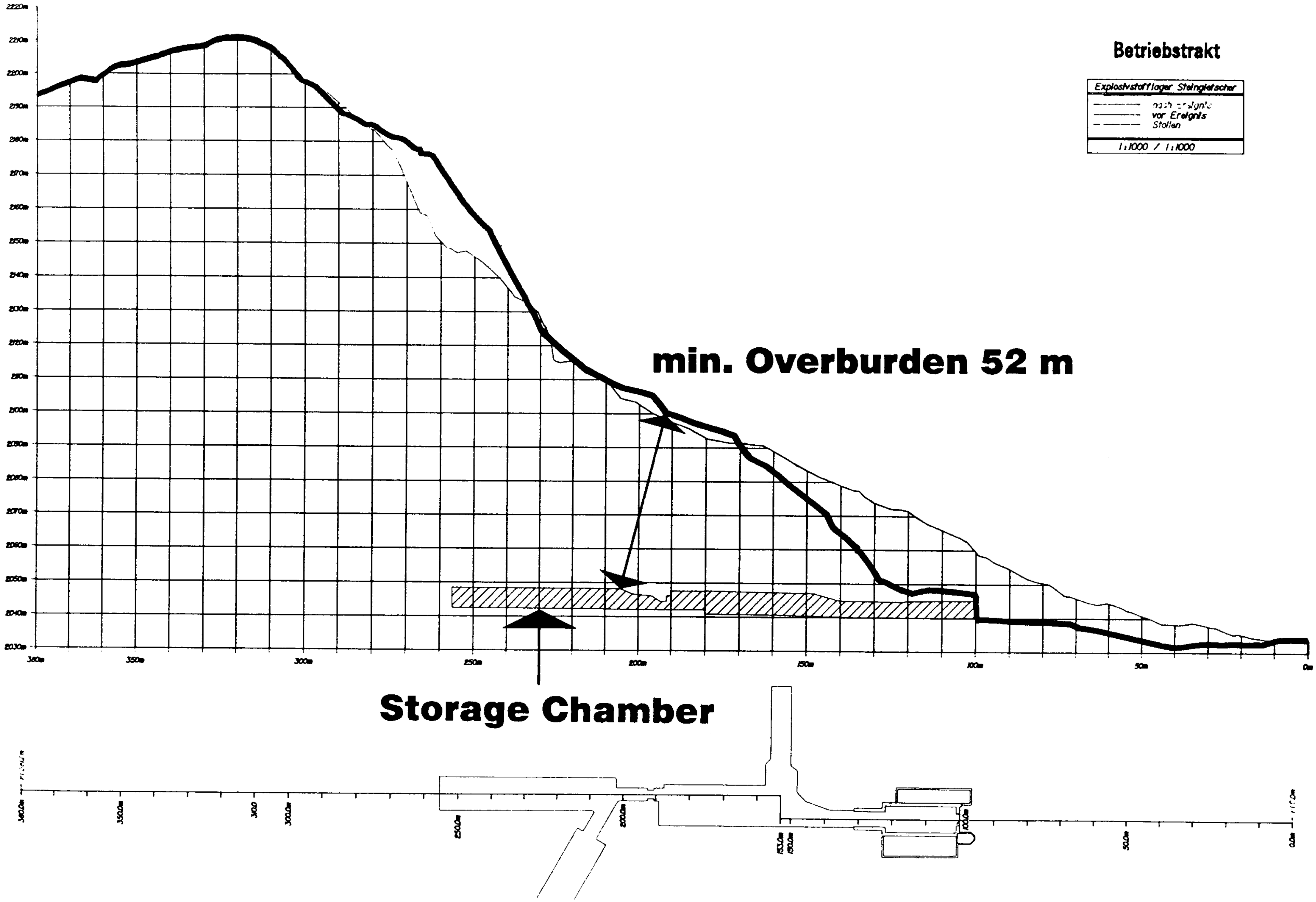




0 50 m

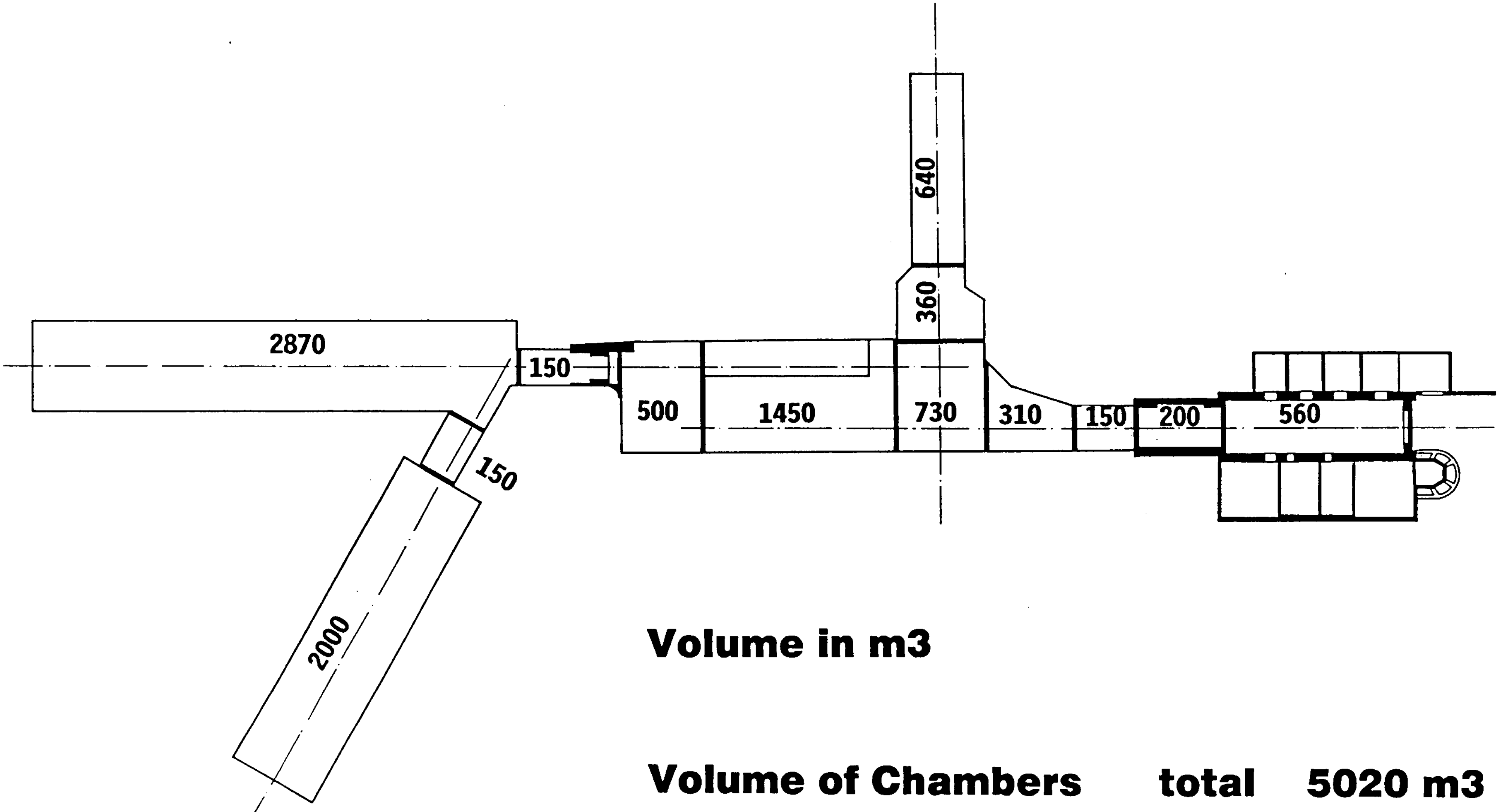
Magazine Layout

Figure 2



Longitudinal Section before and after the Event

Figure 3



Volume in m3

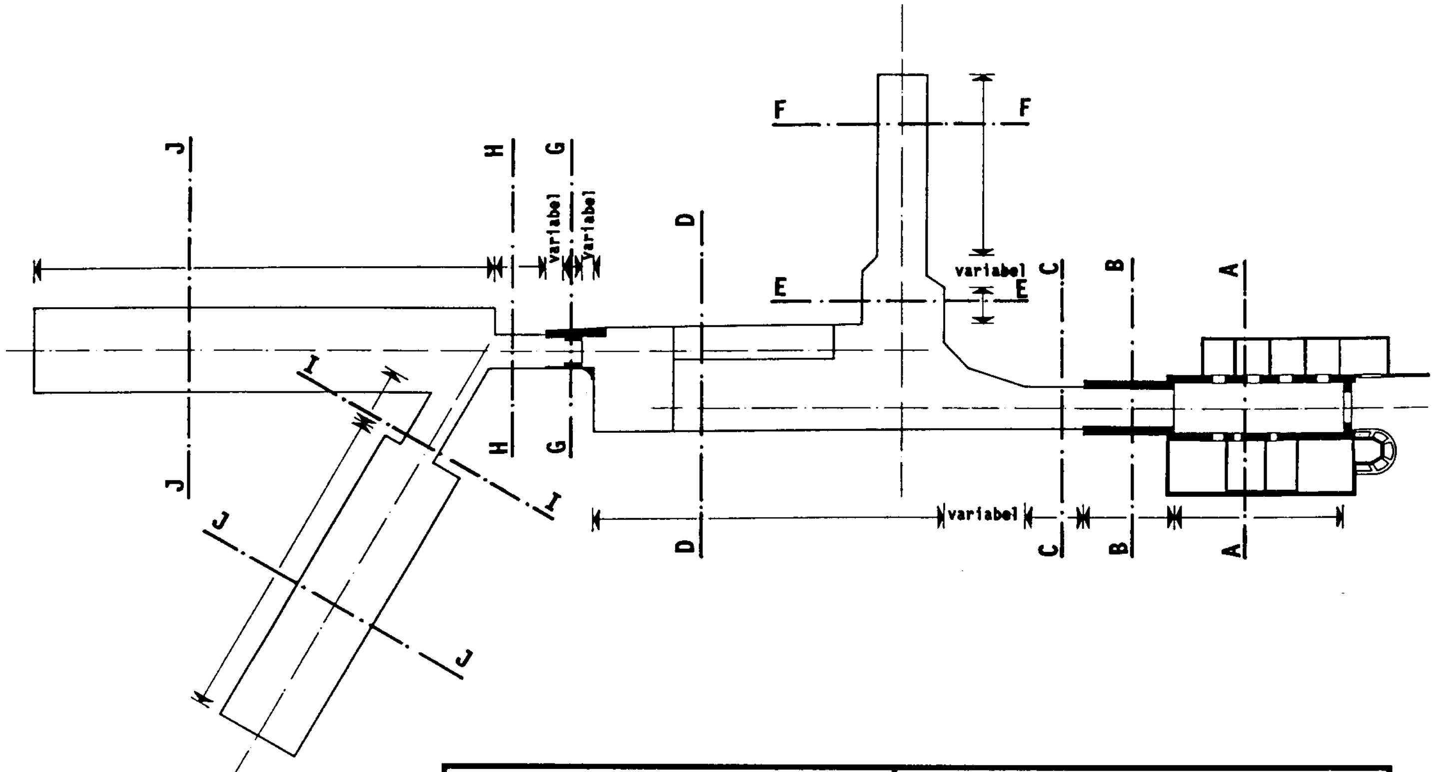
Volume of Chambers total 5020 m3
Volume of Installation total 10070 m3

Volume of Chambers and Tunnel Sections

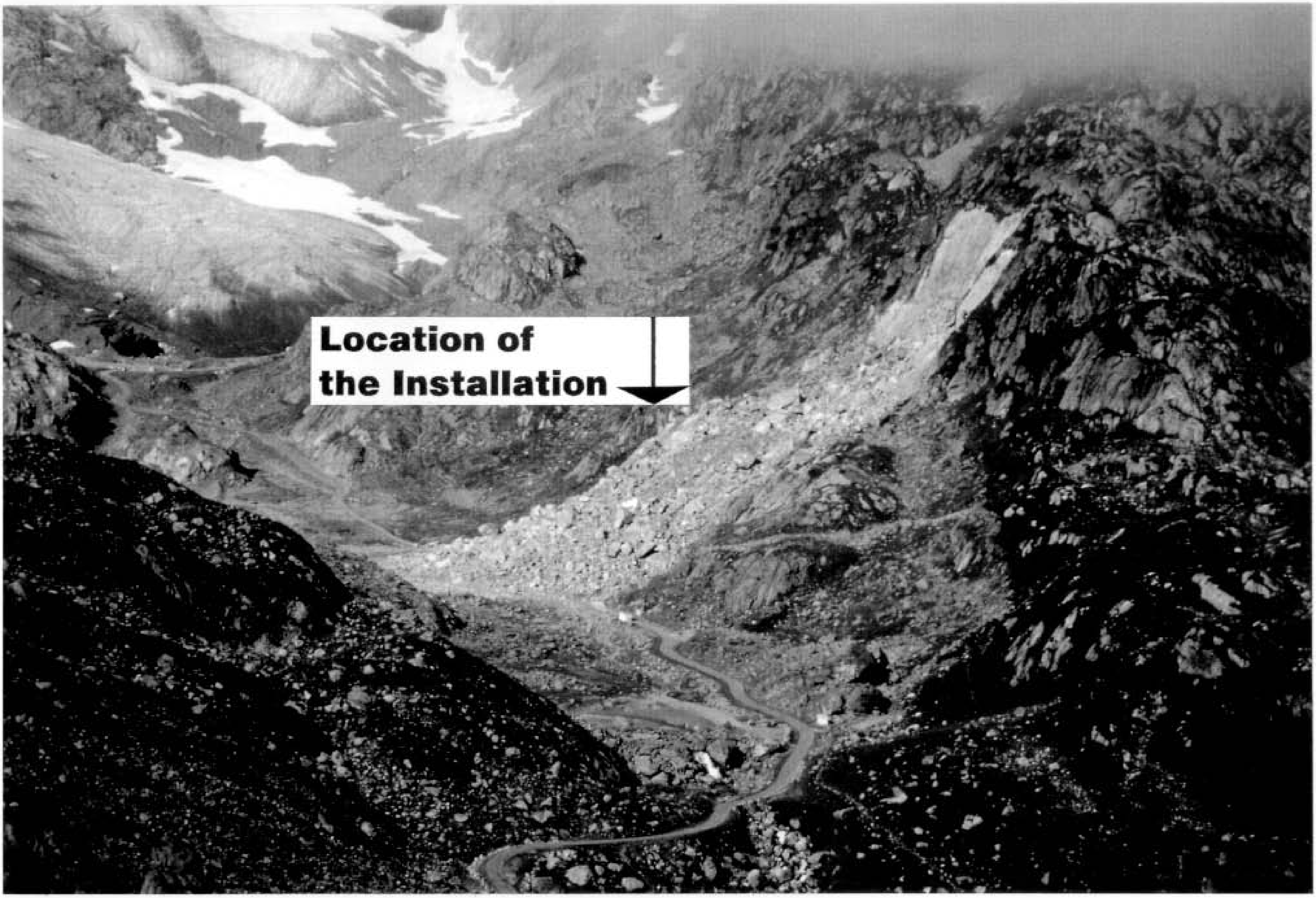
Figure 4

Relevant Cross-Section Areas

Figure 5



Section	Relevant Cross-Section-Areas [m^2]
A - A	27.9
B - B	19.4
C - C	20.6
D - D	68.3
E - E	49.9
F - F	29.9
G - G	6.0
H - H	15.9
I - I	21.7
J - J	52.8



Overview of the Scene after the Explosion

Figure 6 (Taken seven months after the event)

3. Recovery and Documentation of Basic Field Data

The damage pattern as a basis for the evaluation of the physical explosion effects was recorded by topographical maps, terrain sections and aerial as well as terrestrial photos. Detailed documentations were elaborated for 53 large single debris and 40 "debris collection fields" [Ref. 4]. The data from these debris fields were used for the evaluation of the debris throw from the crater and are presented in this paper.

The following main steps were necessary for the recovery of the debris field data:

1. First of all, suitable debris areas showing a characteristic debris distribution had to be selected. This was quite a difficult task as "new" debris had to be found in a desert of stones. In the end however, it was easier than expected as the shape of the crater debris, the vegetation under them at the place where they were found and the "clean" debris surface - without any lichens on it - made a distinction possible. Figure 8 shows two of the chosen fields.

2. The selected fields were marked, photographed and surveyed. The result of this step was an area map containing the installation and all the fields where debris had been collected (fig. 9, nos. 81 to 120, nos. 1 to 53 indicate the location of the recorded large single debris).

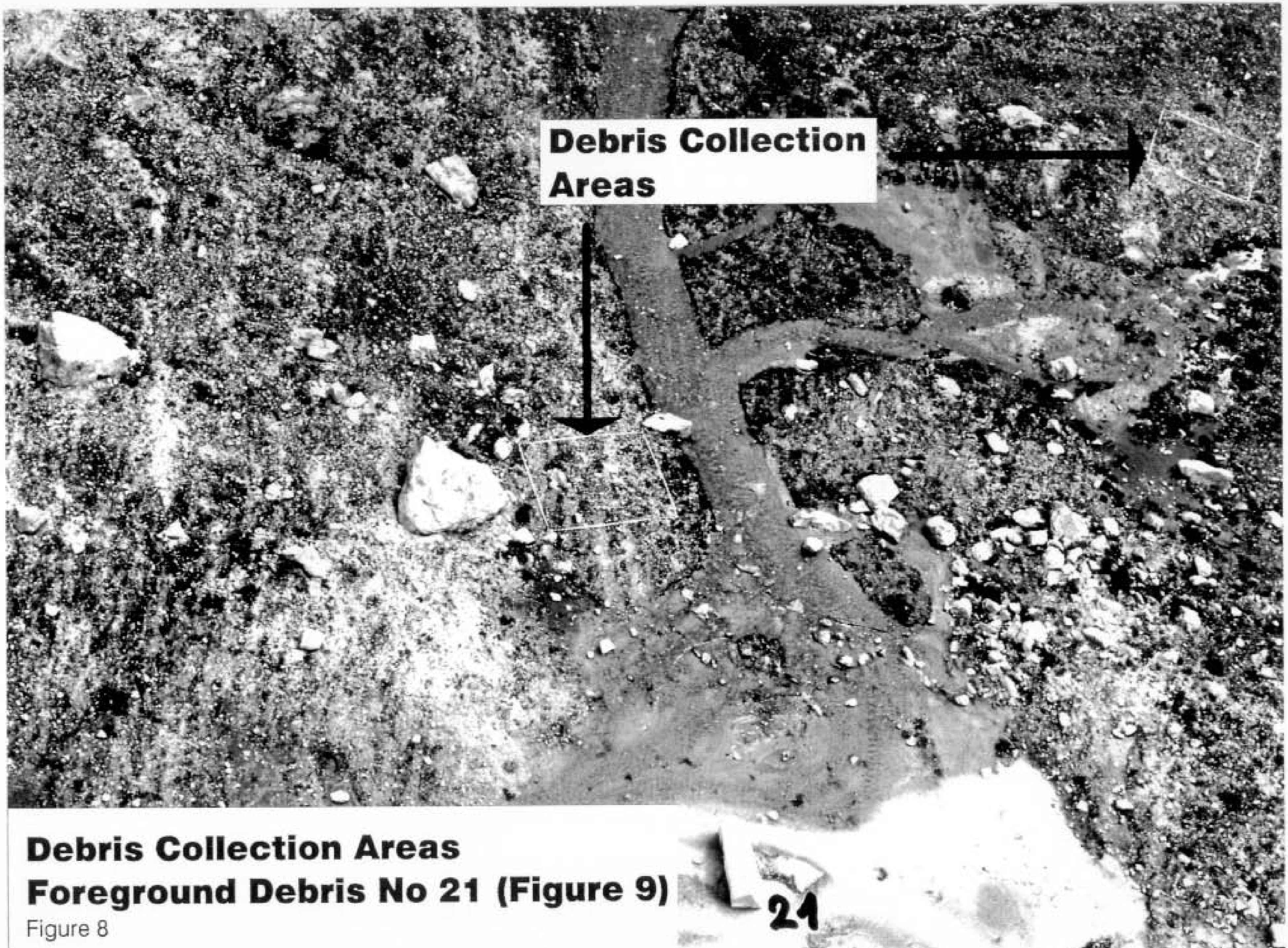
3. At last, all debris were collected, sorted out for different materials (rock, concrete, metal parts etc.) and according to their seize. Figure 10 shows an example. The debris were counted and weighted. Back in the office, for each debris field a data sheet showing all details was elaborated and, as a first step of the evaluation, the debris density in kg/m^2 was defined (fig. 11). Figure 12 gives an overview of the data of all debris fields.

Over all 25 man-days were invested in the data recovery on the spot. This is not as much as would have been desirable but financial and time constraints made a more extensive site investigation impossible. Two things have proofed true again:

1: After an accident there is an urgent need - whoever knows why - to clean up the mess as fast as possible, not only on the spot but also in mind.

2: It's much easier to get a million dollar for a clean new test than 10'000 for the evaluation of an accident (ulterior motive: help us god that they don't find anything we (the responsible persons) might be blamed for!).

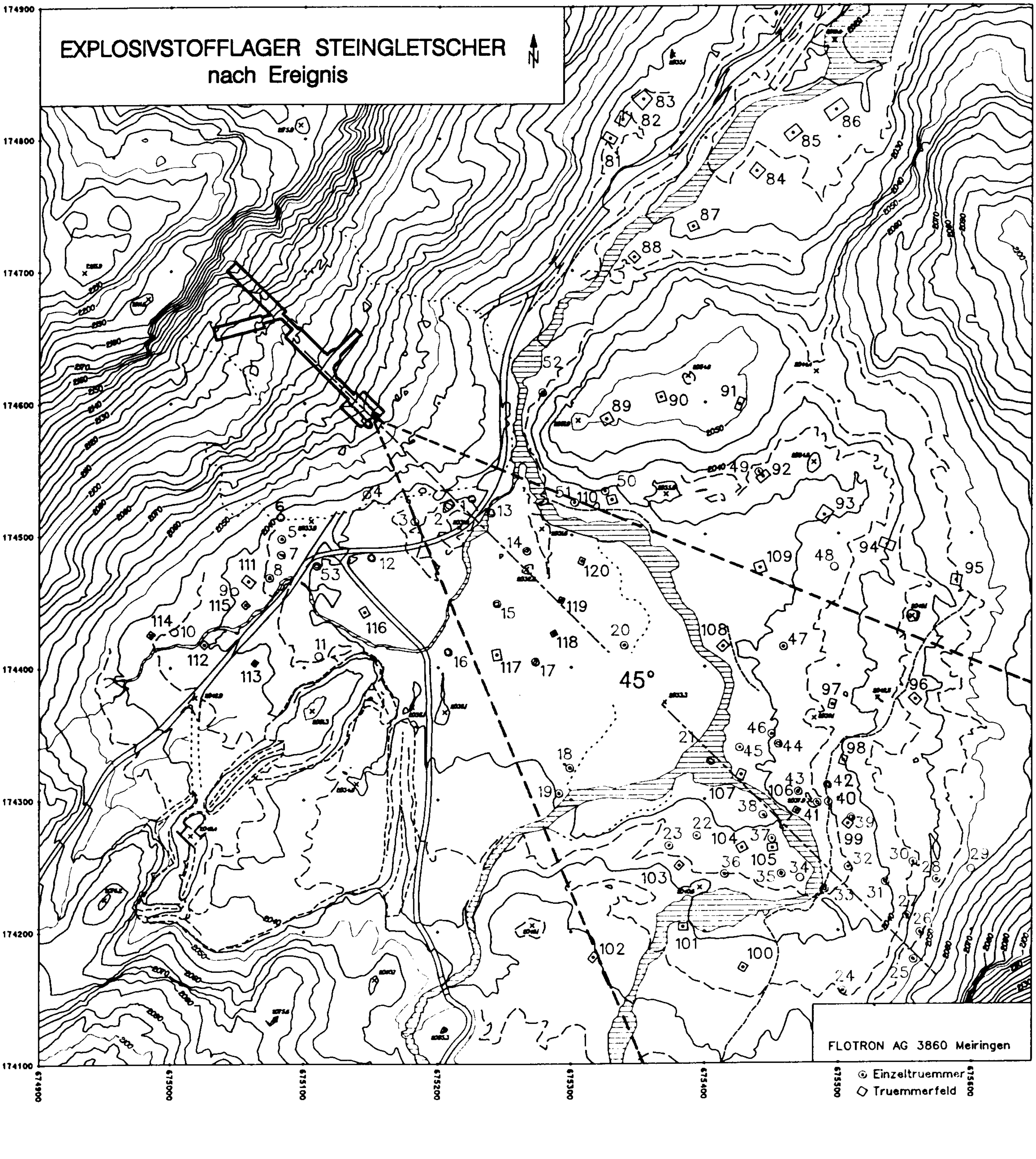
Concrete Block from Entrance Building
Weight 15 tons, 370 m from Original Place
Figure 7



Debris Collection Areas
Foreground Debris No 21 (Figure 9)
Figure 8

New Area Map with "Debris Fields"

Figure 9



Debris from a "Collection Area"
Figure 10

Data Sheet of a "Debris Field"

Figure 11

TRÜMMERFELD	NR. 88
Beschreibung :	Grünes Feld, 1/4 unter Wasser
Ort :	Linke Flanke neben Gletscherbach
Abmessung :	L = 7.45 m B = 6.35 m
Fläche :	F = 47.30 m^2

Art und Masse [kg] der Trümmer:

Anz.	Gewicht Einzel	Gewicht Total	Gew. / Art Total	Art	Bemerkungen
1	32.5	32.5		F	
1	20	20		F	
1	6	6		F	
2	4	8		F	
1	3	3		F	
3	2	6		F	
2	1.5	3		F	
2		2		F	
4		4		F	
12		8		F	
10		4		F	
10		3		F	
10		2		F	
Rest		10	111.5	F	
		0.05		M	
1	1	1	1.05	M	
		0.3	0.3	H	
Total		112.85			

Trümmerdichte [kg/m^2] Total: 2.38

Fels: 2.36   Beton: H: 0.0063   Metall-/Munitionsteile: 0.022

Bemerkungen :	- 1 Zünder 15,5 cm, ca 1 kg
Erhoben am :	28.7.93

Data of all Debris Fields

Figure 12 a

OVERVIEW DEBRIS FIELDS							
Debris Field		Coordinates		Distance to	Distance to	Altitude	Debris
no.	Location	Y [m]	X [m]	Portal [m]	Center of Crater [m]	Above Sea Level [m]	Density [kg/m2]
81	a	5328.0	4799.7	276.3	279.0	2033.5	2.45
82	a	5337.6	4814.1	293.5	294.5	2032.6	1.00
83	a	5352.9	4829.3	315.0	315.5	2032.1	0.38
84	a	5437.7	4774.5	342.2	370.3	2022.9	1.03
85	a	5464.8	4803.1	380.7	405.1	2021.1	0.23
86	a	5497.5	4820.0	417.2	441.7	2021.1	0.06
87	a	5390.3	4732.8	279.9	313.6	2024.1	0.91
88	a	5346.2	4709.9	230.3	265.8	2026.7	2.39
89	a	5325.8	4587.6	174.7	253.1	2050.5	2.17
90	a	5366.4	4604.1	215.9	288.2	2050.5	3.69
91	a	5425.0	4598.4	274.1	346.8	2050.3	1.32
92	a	5442.8	4543.5	295.0	378.0	2036.3	1.23
93	a	5488.8	4514.3	345.5	431.1	2035.2	1.15
94	a	5536.1	4491.5	396.7	483.4	2040.5	0.76
95	a	5587.9	4464.4	453.8	541.5	2047.1	0.77
96	i	5557.2	4374.6	458.5	554.2	2044.2	1.38
97	i	5495.1	4371.0	406.4	504.3	2038.9	1.33
98	i	5503.3	4328.7	437.0	536.4	2039.8	3.38
99	i	5506.8	4280.7	469.7	570.2	2037.9	4.80

a = Debris fields outside 45° angle

i = Debris fields inside 45° angle (area where debris from access tunnel dominates)

Data of all Debris Fields

Figure 12 b

OVERVIEW DEBRIS FIELDS							
Debris Field		Coordinates		Distance to	Distance to	Altitude	Debris
no.	Location	Y [m]	X [m]	Portal [m]	Center of Crater [m]	Above Sea Level [m]	Density [kg/m2]
100	i	5428.2	4172.3	499.1	599.7	2041.3	3.68
101	i	5383.5	4203.4	448.9	548.9	2040.7	3.09
102	(a)	5316.4	4180.5	439.2	536.0	2045.4	6.72
103	i	5380.6	4249.7	408.3	509.0	2038.7	5.86
104	i	5427.3	4263.2	425.9	527.2	2036.7	8.46
105	i	5450.2	4263.0	441.2	542.5	2035.6	4.63
106	i	5468.2	4290.9	434.1	535.0	2035.5	8.34
107	i	5426.6	4318.4	385.0	486.1	2034.3	9.29
108	i	5412.9	4415.2	313.3	411.9	2033.5	4.66
109	a	5440.6	4474.4	310.8	403.3	2034.0	1.38
110	a	5329.8	4526.5	188.8	281.1	2034.7	3.38
111	a	5057.8	4464.9	154.0	200.6	2039.7	4.26
112	a	5024.9	4417.2	211.9	253.6	2040.9	3.66
113	a	5062.8	4403.2	204.3	261.4	2041.2	3.54
114	a	4984.9	4424.8	232.5	258.8	2043.2	2.06
115	a	5055.8	4447.1	169.6	218.5	2039.7	8.30
116	a	5144.4	4441.5	146.1	230.1	2034.5	3.66
117	i	5243.4	4409.5	200.4	299.8	2033.6	5.39
118	i	5286.4	4425.5	211.0	312.3	2033.4	15.34
119	i	5292.1	4450.5	196.5	297.6	2033.1	11.22
120	i	5307.2	4480.1	189.4	288.7	2032.8	6.89
		Coordinates Portal:		5'151.13	Coordinates Cratercentre:		5084.42
				4'587.42			4663.68

4. Evaluation of Basic Data

Based on the results of the field data, until now the following evaluations have been made:

1. Elaboration of a debris density contour map
2. Defining the number of hazardous debris per unit area
3. Estimation of lethality based on the number of hazardous debris

4.1 Debris Density Contour Map

For the development of the contour map, showing the density of debris coming from the crater above the storage chamber, only those debris fields could be used which were not influenced by debris coming out of the access tunnel. Because at the day of the explosion the surrounding of the installation already was covered with snow and with the help of an aerial photo taken 4 days after the event, it was easy to sort them out. Therefore, all debris fields lying within 22.5 degrees to the left and right of the axis of the tunnel entrance were not used for further evaluation. This 45 degree angle is, by the way, exactly the area in which our safety regulation TLM 75 [Ref. 6] expects most of the debris coming from an access tunnel. For further evaluation of the debris throw from the crater only the debris fields nos 81 to 95 and 109 to 116, a total of 23 were used. Together with the fact that the maximum crater debris throw distance was in the order of magnitude of 600 to 700 m, the graph in figure 13 was elaborated. Although the data scattering was not as small as we would have liked it, the debris mass density versus distance curve represents the physical facts, in our view, reasonably well. Based on this curve the debris mass density contour lines in figure 14 could be drawn as a final result.

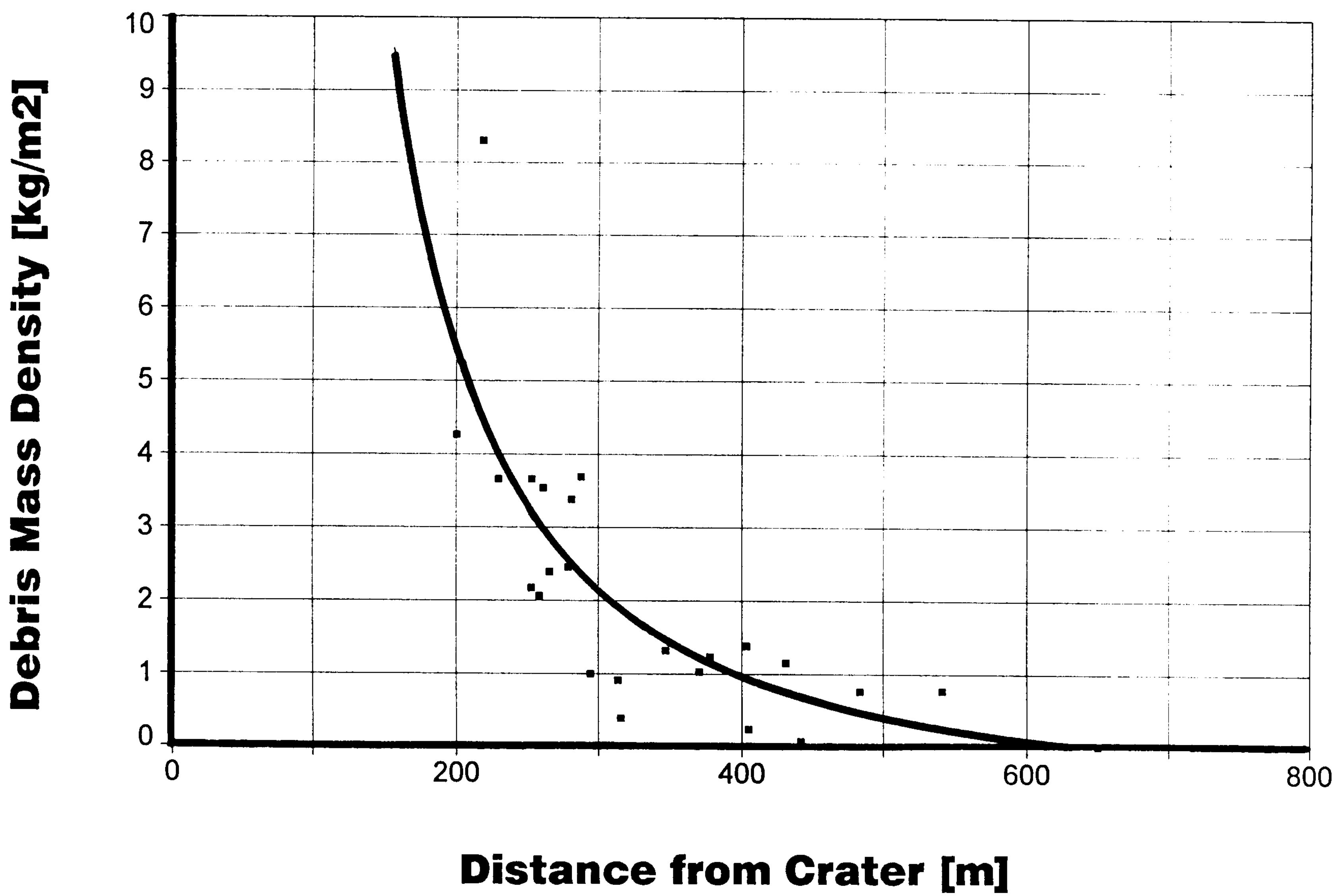
4.2 Defining of Number of Hazardous Debris per Unit Area

Debris density contour lines are only one step on the way to determine a safety distance or a lethality rate for a person exposed to this physical effect. In fact there are always one single or a couple of lethal debris responsible for taking life and not a debris density per m^2.

Thus, the next step in our evaluation was to establish the number of hazardous debris belonging to a certain debris density. Based on the data sheets of the debris fields (fig. 11) a debris size summation curve was developed for each field. A summary of the curves of all 23 fields is shown in figure 15. A regression with these data points was made (fig. 16) and a final average distribution of the debris size (mass) versus number of debris - standardized for an area of one m^2 and a debris density of 1 kg per m^2 - was the result. Of course it was tested if the debris size distribution is dependent on the distance from the crater or the angle from the tunnel axis, but neither of them was the case.

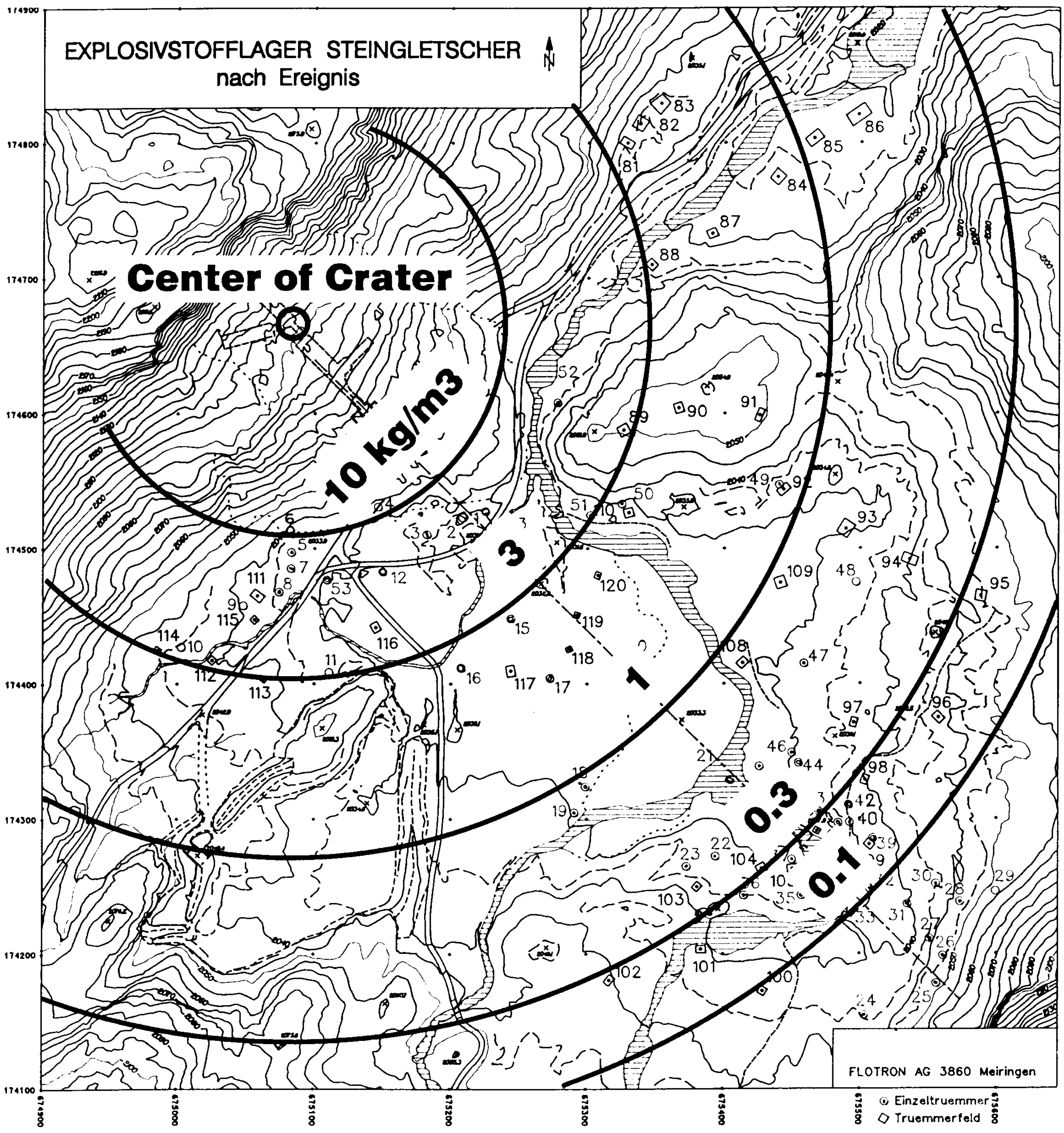
Debris Mass Density versus Distance from Center of Crater

Figure 13



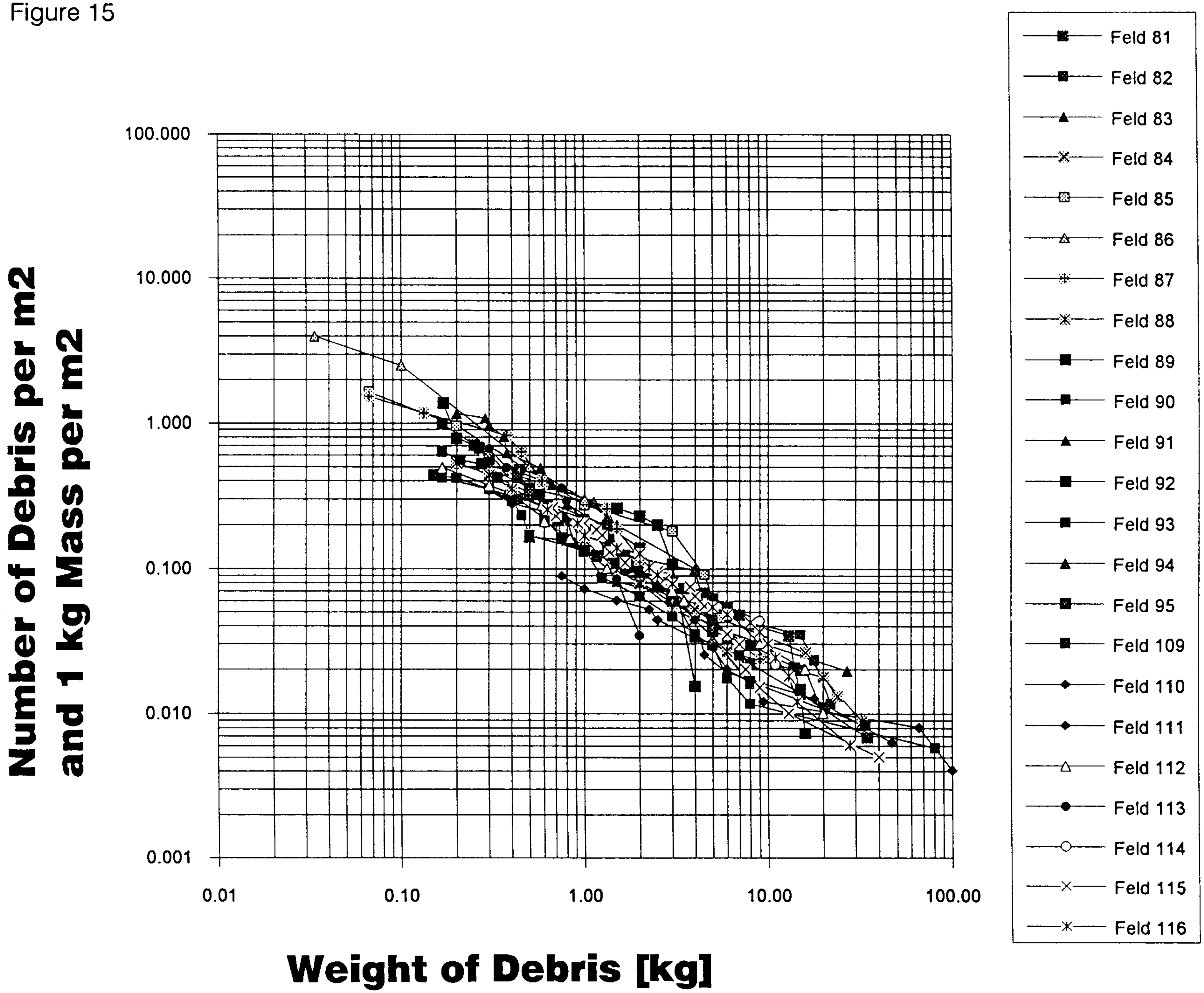
Debris Mass Density Contour Lines

Figure 14



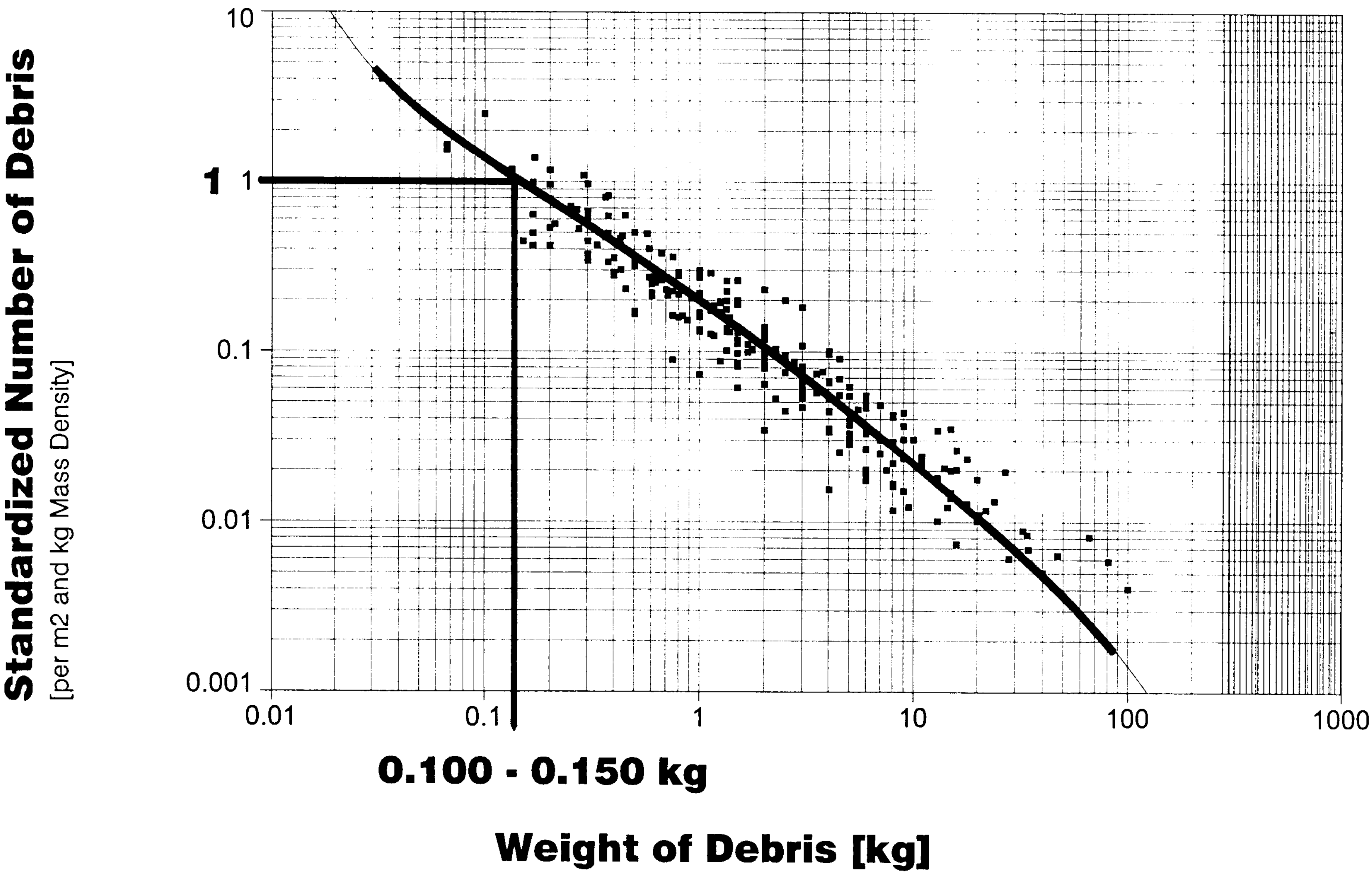
Summary of Debris Size Distribution of all Debris Fields

Figure 15



Medium Debris Size Distribution

Figure 16



But what is a hazardous debris? According to the NATO regulations a hazardous debris is a piece of material with a kinetic energy of more than 79 joules. Taking into account an endballistic velocity in the range of 35 - 50 m/s, it can be concluded that all debris with a weight of more than 100 to 150 g are lethal. The long and the short of it is that in figure 16 you can read that for a debris density of one kg per m^2 you get the average of 1 lethal debris per m^2. Of course, this value is not an universal constant, it is only valid for the type of rock being in the Steingletscher area.

4.3 Estimation of Lethality Based on the Number of Hazardous Debris

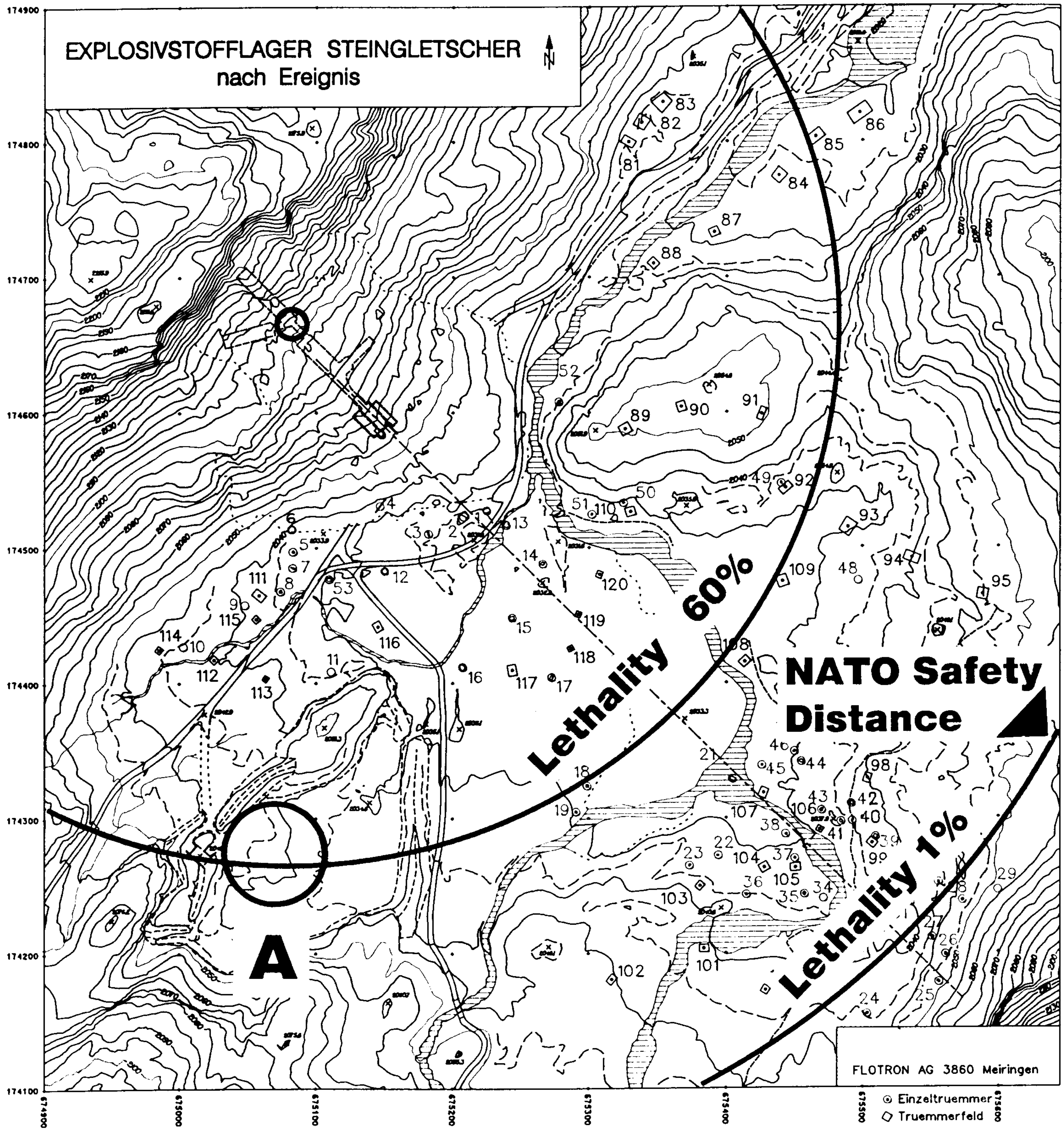
With the values gained until now, and according to the NATO safety principles, it is easy to calculate the "Safety Distance" based on the criterion of one hazardous debris per 600 ft^2 respectively 55.7 m^2. According to figure 13 you would come up with a safety distance of 640 m (fig. 17). The lethality of a person standing in the open at that "Safety Distance" - taking into consideration a lethal area for a person of 0.58 m^2 according to the NATO regulations (a relatively large area for a standing man facing the explosion) - would be around 1%. For the contour line indicating a debris density of 1.0 kg/m^2 the respective lethality value would then be around 60 %.

But how do these lethality figures compare with reality? At the time of the explosion 6 workers were standing in the open at point A in figure 17. No one was hurt! Being aware that we are dealing with probabilities, the chance that this happens is not zero, however very little. That's why we are convinced that the NATO safety criteria are over conservative in this case.

How would we judge this situation according to the Swiss Safety Regulations? As you may know, we do not have safety distances, but calculate the risk quantitatively (Ref. 8, 9). This approach gives a much better picture on what really happens. Thus, the technical models like lethality as a function of physical effects have to be more extensive and detailed than in a Q-D approach. Therefore, several years ago the lethality of persons due to debris throw coming from a crater was studied in-depth (Ref. 5 and 7). Taken into account were, for example, the impact angle of debris and the different susceptibility of different parts of the body. Figure 18 shows that the impact of a debris with an energy of 79 joules results in a considerable lethality only in case the head is hit. Other parts of the body are less sensitive to debris impact with respect to lethality. Based on that model and for the debris density measured at the Steingletscher site - taking into account the distribution of the debris size according to figure 16 - the lethality was calculated. Coming up with a lethality of less than 10 % at point A (fig. 19), we are confident to judge this situation more realistic.

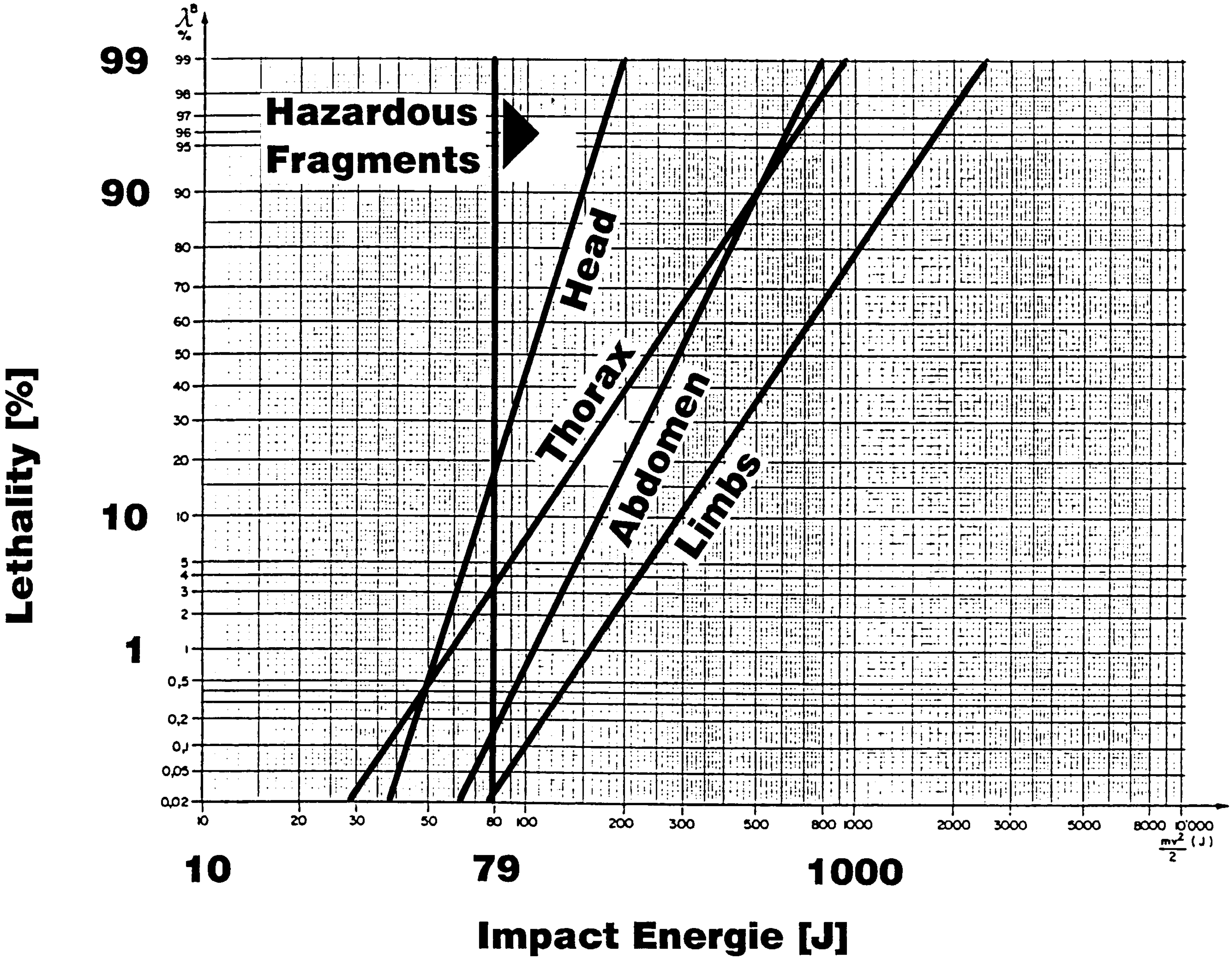
Lethality According to NATO Safety Criteria

Figure 17



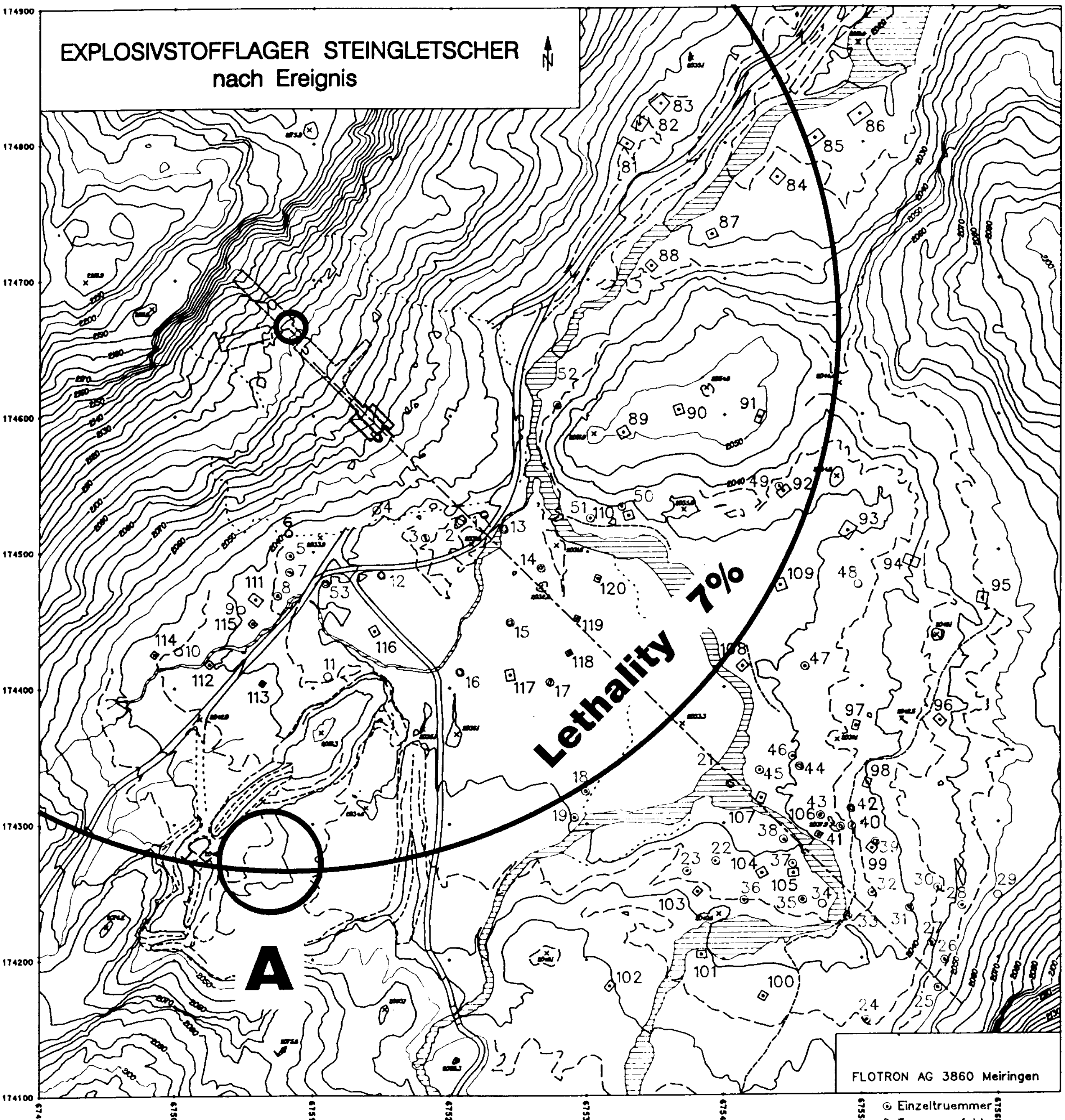
Lethality versus Impact Energie

Figure 18



Lethality According to Swiss Criteria

Figure 19



5. Final Remarks

This paper presented the technical evaluation of the debris throw coming from the crater above an underground ammunition storage installation. Concerning the debris throw of such an installation, this is only half of the problem. As the Steingletscher accident demonstrated, debris throw from the access tunnel can be even more intensive and in many cases it may be the decisive effect. In a further step it is therefore intended to evaluate the debris throw from the access tunnel in the same way - but this can only take place as soon as the judges and lawyers make the necessary data available.

Concerning this evaluation we could learn the following lessons:

1. An accident is a tragedy for the victims. But it is an unique opportunity for the safety specialists to check and improve their instruments for the safety assessment.

2. It is not easy for a technical expert to get to the facts. There is an urgent need to clean up the site immediately, and judges and lawyers tend to lock away important facts for a very long time.

3. Even with a limited set of data valuable scientific findings can be made, for which prohibitively expensive test would be necessary.

On the technical level it could be shown based on a realistic case that the NATO safety criteria for debris throw might be over conservative, as suspected by many experts. Furthermore it is shown that the Swiss approach for the lethality due to debris throw from a crater gives more plausible results, and therefore together with the risk based approach allows in the end a more economic use of the installations.

References

1. **Accident Investigation at the Swiss Steingletscher Installation**
   Hansjörg E. Rytz, Peter O. Kummer, Joseph Jenus, Jr., Khosrow Bakhtar
   Paper presented at the 26th DDESB Seminar 1994 Miami/FL

2. **The Explosion in the Underground Explosives Storage magazine in the Swiss Alps on November 2, 1992**
   TM 111-7, 20 October 1993, P. Kummer / Bienz, Kummer & Partner Ltd.
   Contribution to the 18th Klotz-Club Meeting 1993, Stockholm/Sweden

3. **Description and Geometry of the Installation**
   TM 111-12, September 1995, P. Kummer / Bienz, Kummer & Partner Ltd.
   Contribution to the Klotz-Club Meeting 1995, Thun/Switzerland

4. **Documentation of the Observed Damage**
   TM 111-11, September 1995, P. Kummer / Bienz, Kummer & Partner Ltd.
   Contribution to the Klotz-Club Meeting 1995, Thun/Switzerland

5. **Letalität von Personen infolge Kraterauswurf**
   B 3113-2, Überarbeitete Fassung, Oktober 1984
   Swiss Defence Technology and Procurement Agency / Ernst Basler & Partner Ltd.
   (Lethality of Persons due to Debris Throw from Craters
   B 3113-2, Revised Edition, October 1984)

6. Schweizerische Armee
   Technische Vorschriften für die Lagerung von Munition (TLM 75)
   Teil 1 (Rev 86): Allgemeine Grundsätze
   Teil 2 (Rev 90): Sicherheitsbeurteilung von Munitionslagern
   Teil 3 (Rev 86): Planung und Projektierung von Munitionslagern
   Teil 4 (Rev 93): Friedensmässige Belegung von Munitionslagern
   Teil 5: Sicherheitstechnische Vorschriften für den Umgang mit Munition bei der Truppe
   (Technical Regulations for the Storage of Ammunition 75
   Part 1 (Rev 86): General Principles
   Part 2 (Rev 90): Safety Assessment of Ammunitions Stogarges
   Part 3 (Rev 86): Planning and Construction of Magazines
   Part 4 (Rev 93): Storing of Ammunition in Peace Time
   Part 5 Storing of Ammunition by the Troops)

7. **Lethality of Unprotected Persons due to Debris and Fragments**
   Paul W. Janser for Ernst Basler & Partner Ltd.
   Paper presented at the 20th DDESB Seminar 1982, Norfolk/VA

8. **How the Safety of the Ammunition and Explosives Storages and Handling is Managed in Switzerland**
   Safety Concept, Regulations and Organisation
   Andreas F. Bienz and Peter O. Kummer / Bienz, Kummer & Partner Ltd.
   Paper presentet at the 25th DDESB Seminar 1992, Anaheim/CA

9. **How the Safety of the Ammunition and Explosives Storages and Handling is Managed in Switzerland**
   Risk Analysis of Ammunition Magazines
   Peter O. Kummer and Andreas F. Bienz / Bienz, Kummer & Partner Ltd.
   Paper presentet at the 25th DDESB Seminar 1992, Anaheim/CA